REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-01-0188

1. REPORT DATE (*DD-MM-YYYY*)	2. REPORT TYPE	3. DATES COVERED (*From - To*)
1-Jun-1999	Interim	1994 - 1998

4. TITLE AND SUBTITLE
Preoxygenation time versus decompression sickness incidence

5a. CONTRACT NUMBER
F33615-92-C-0018 and F41624-97-D-6004

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHORS
James T. Webb, Ph.D., Andrew A. Pilmanis, Ph.D., and Kevin M. Krause, Ph.D.

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
58

5f. WORK UNIT NUMBER
01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Wyle Laboratories, Life Sciences, Systems and Services Inc.
2485 Gillingham Drive
San Antonio, TX 78235-5105

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
High Altitude Protection Research
Aircrew Protection Branch
2485 Gillingham Drive
San Antonio, TX 78235-5105

10. SPONSORING/MONITOR'S ACRONYM(S)
AFRL/HEPR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-BR-JA-1998-0053

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release

13. SUPPLEMENTARY NOTES
This report was published in the SAFE Journal 1999;29:78-78.

14. ABSTRACT
The cabin altitude experienced by U-2 pilots during high altitude reconnaissance missions is approximately 30,000 ft. Increasing the duration of preoxygenation, breathing 100% oxygen prior to decompression to reduce the incidence of decompression sickness (DCS), increases denitrogenation but is impractical due to mission time constraints and crew duty limitations. Use of exercise-enhanced preoxygenation instead of increasing the duration of preoxygenation to provide better protection from DCS has been successfully demonstrated in the laboratory. This report describes the first operational use of the new procedure. A U-2 pilot, who had previously reported serious DCS symptoms resulting in mission aborts during two of his first twenty-five high altitude flights, volunteered to operationally try the exercise-enhanced preoxygenation procedure. His next 28 U-2 high altitude flights incorporated moderate aerobic upper and lower body exercise at a controlled rate during the first 10 min of a 90-min preoxygenation. The total preoxygenation time was of the same duration as accomplished prior to his last aborted mission. The pilot reported no DCS symptoms during the subsequent 28 high flights. An operational trial of exercise-enhanced preoxygenation has been shown to be feasible under operational constraints and, to date, has been successful.

15. SUBJECT TERMS
decompression sickness, venous gas emboli, exercise, prebreathe, preoxygenation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19A. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER (*Include area code*)
U	U	U	UU	4	James T. Webb / 210-536-3439

PREOXYGENATION TIME VERSUS DECOMPRESSION SICKNESS INCIDENCE

James T. Webb, Ph.D.*
Andrew A. Pilmanis, Ph.D.
Air Force Research Laboratory
Biodynamics & Protection Division
* Wyle Laboratories, Life Sciences, Systems and Services
Brooks AFB, TX 78235-5104

ABSTRACT

Preoxygenation, breathing 100% oxygen prior to decompression, has been used for well over half of this century to reduce decompression sickness (DCS) incidence. Duration of preoxygenation has been reported to be inversely related to subsequent DCS incidence. A direct comparison of DCS incidence at 30,000 ft versus preoxygenation time is needed to allow better-informed decisions regarding the cost vs. benefit of increasing preoxygenation time to prevent DCS. To obtain such a comparison, we accomplished a retrospective study of exposures to 30,000 ft (226 mm Hg; 4.37 psia) while performing mild exercise. The 86 male exposures were preceded by preoxygenation times of one to four hours. Venous gas emboli (VGE) and DCS symptom development were monitored and recorded. Although more protection was demonstrated with increasing preoxygenation time, the cost-to-benefit ratio also increases with each additional increment of preoxygenation time. The diminishing return of increasing preoxygenation to reduce DCS would eventually impact mission planning and crew duty limitations. Alteration in the physiology of denitrogenation, such as inclusion of exercise during preoxygenation, may provide better and more cost-effective DCS protection than simply increasing preoxygenation time.

INTRODUCTION

The risk of DCS is related to the supersaturation of tissues with nitrogen as the body is decompressed from a ground-Although the solubility coefficient of nitrogen is about half that of oxygen, tissue metabolism utilizes inspired oxygen, reducing the oxygen concentration to a level which is not a determining factor in development of tissue gas emboli during decompression. However, reducing the tissue nitrogen concentration at ground level reduces risk of DCS because it reduces the level of supersaturation during decompression. If 100% oxygen is breathed ground level (preoxygenation or prebreathing), tissue nitrogen diffuses into the nitrogen-free blood and is carried to the lungs for expiration, following a diffusion gradient from the blood to the alveolar spaces. Lowering tissue nitrogen content in advance reduces the level of supersaturation during decompression and thus provides protection from DCS.

This paper was received for review on 31 October 1998 and accepted for publication on 11 February 1999.

The value of preoxygenation for altitude DCS protection was described by Behnke (1), who reported that 95% of body nitrogen was removed in four hours and 98% in six hours. The relationship between preoxygenation time and subsequent DCS incidence was described by Ferris et al. (3) and Grey (4). As shown in Figure 1, their findings indicate a non-linear relationship between preoxygenation time and symptom incidence.

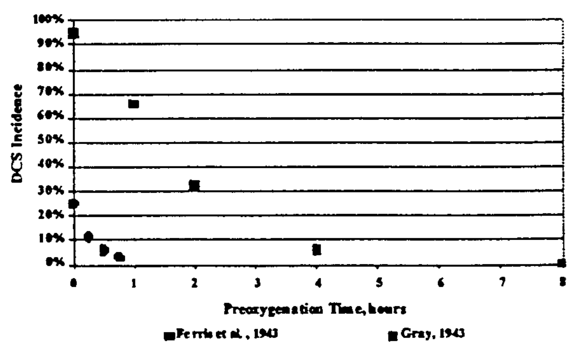

Figure 1. DCS incidence versus duration of preoxygenation. WWII data.

Although both data sets are based on "forced descents" (intolerable bends or chokes) of subjects exposed to 35-38,000 ft for 2-3 hours, the large difference in observed

incidence of DCS requires explanation. These data sets are different because the one by Ferris et al. (3) resulted from exposures of exercising subjects versus the data from from Gray (4) which resulted from resting subjects. These results are not compared with present day results because the endpoint DCS symptom criteria were very different. During WWII, much more severe symptoms were allowed to develop prior to recompression.

Figure 2 shows the results of Waligora et al. (7) with six-hour exposures to 30,000 ft following 3.5-8 hours of preoxygenation (N varied from 8 to 38). The linear regression line shows a high correlation. Although the Waligora paper did not suggest relevance of their data to preoxygenation times less than 3.5 hours, extrapolation of the linear regression line suggests a level of 35% DCS with one hour of preoxygenation.

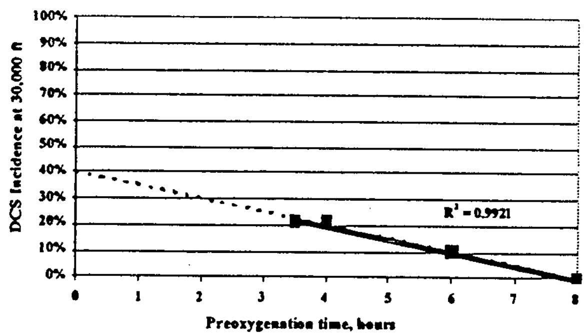

Figure 2. DCS incidence versus duration of preoxygenation. Waligora et al. (7) data; Confidence Interval ≤ 17%

If we can improve our understanding of the process of denitrogenation by preoxygenation as it relates to DCS risk, we could more accurately define the cost/benefit ratio. With a better-defined cost/benefit ratio, we could more accurately answer the questions we are asked on a monthly basis regarding how much to increase preoxygenation to achieve a given level of DCS. Howerver, the well-defined exponential relationship between preoxygenation time and nitrogen washout does not equate directly to DCS protection. Although more preoxygenation has repeatedly been shown to provide better protection, the cost of additional time spent preoxygenating may not be repaid by a reduction in DCS incidence of perceived equal value. How much time is available and how much that time costs are as much factors in recommending preoxygenation time as is the acceptable incidence of DCS for a given mission scenario. The acceptable incidence of DCS must ultimately be determined by operational commanders in consult with flight medicine specialists.

We have used 5% and 50% DCS (6) as levels of concern for operational activities. During exposures which result in 5% DCS, virtually no serious DCS is observed in the laboratory. Conversly, when 50% DCS is observed in the laboratory, serious symptoms appear with some degree of regularity. These levels, 5% and 50% can be used as bases for decisions involving cost/benefit ratios.

METHODS

The data used in this study were aquired from three exposure profiles recorded in the AFRL Hypobaric DCS Database at Brooks AFB, TX. The profiles used were limited to those involving exposures to 30,000 ft for four hours while performing mild exercise as described in Webb et al. (8). The subject pool for the AFRL studies varied from 26 to 30 males. Microsoft Excel 97 linear regression and exponential trendlines were used to display relationships between values and to provide coefficients of determination (R^2 where R= Correlation coefficient).

RESULTS

The data from Waligora's study (7) and the AFRL data are consistent within each study, but reveal differences which may be due to symptom classification and/or reporting. At AFRL, some symptoms were categorized as DCS which may not have been recorded as such under NASA protocols.

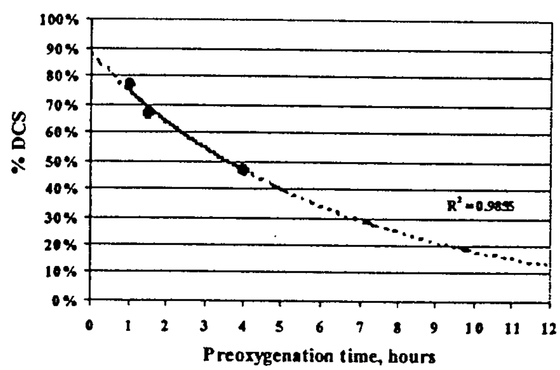

Figure 3. DCS incidence at 30,000 feet versus duration of preoxygenation. AFRL data; Confidence Interval ≤ 18%

With 77% DCS after one hour and 47% DCS after four hours of preoxygenation, extrapolation of the exponential curve in Fig. 3 shows 25% DCS after eight hours of preoxygenation. This curve demonstrates that each additional hour of preoxygenation provides less additional protection. Indeed, analysis of the full AFRL database of more than 2000 exposures using a loglogistic model (5) indicates an exponential relationship exists between preoxygenation time and DCS incidence, similar to the plot in Fig. 3. Despite the diminishing returns of increasing preoxygenation time, it is notable that, with four hours of preoxygenation, virtually no serious symptoms were observed.

DISCUSSION

The plot in Fig. 3 shows an expanded X-axis to 12 hours so that the probable true shape of the relationship becomes evident. As shown in Fig. 3, the non-linearity of DCS incidence versus preoxygenation time does not become apparent until at least four hours of preoxygenation. Therefore, for practical usage, it is reasonable to assume a linear relationship over the range of preoxygenation times used during current USAF or NASA operations.

However, the drop in DCS risk during that linear range (0-4 h) is approximately 30%, i.e. 76% to 47%. Thus, even with four hours of preoxygenation, which is operationally unacceptable in most cases, almost half of the population will develop DCS. With more than four hours of preoxygenation, the benefit will become even less per additional hour of preoxygenation. For example, to get below 10% DCS would require well over 12 hours of preoxygenation.

Current USAF high altitude reconnaissance operations (U-2 flights) use a one-hour preoxygenation (2). Responses to an anonymous survey of active/retired U-2 pilots indicated 70% of the pilots had experienced DCS at least once during their career. Our results indicate 77% incidence during analogous research chamber experiments (8). It is notable that many of the symptoms observed during our laboratory studies are very mild and may not be noticed by crewmembers. Also, our subjects are extensively briefed to tell us about any change in their well-being, whereas crewmembers are usually very reluctant to report symptoms which, particularly in the past, could result in cessation of their careers.

Regardless of the reporting issue and mild vs. significant symptoms, the survey indicated a problem with the one-hour preoxygenation. The use of more preoxygenation has limited value and potential alternatives are worth pursuing. One method to improve preoxygenation effectiveness has been successfully tested both in the laboratory and during limited operational test and evaluation. This method (8) involves use of exercise to increase perfusion, ventilation, and diffusion during preoxygenation.

CONCLUSIONS

DCS incidence versus preoxygenation times of less than four hours yield linear regression and exponential plots which are nearly superimposed. Divergence of the plots does not become evident until preoxygenation time exceeds four hours. The slow washout of nitrogen from tissues like bone and tendons is reflected in the shape of the incidence versus time curves which are somewhat analogous to a half-life plot. The slow washout causes a diminishing return when merely increasing preoxygenation time to increase protection from DCS and explains why some DCS has still been observed at 30,000 ft after six hours of preoxygenation.

Based on the information presented, increasing preoxygenation time beyond approximately one hour for exposures to 30,000 ft would increase the cost/benefit ratio of DCS protection. However, there may be an alternative. Improved nitrogen washout rate can be achieved with exercise-enhanced preoxygenation. A 10-min period of strenuous exercise at the beginning of a one-hour preoxygenation does not involve an increase in fatigue and significantly reduces DCS incidence to the equivalent of a four-hour resting preoxygenation (9). Indeed, this procedure has been incorporated into current NASA research testing and evaluation aimed at more efficient extravehicular activity for building the International Space Station and into current USAF operational testing and evaluation aimed at better protection during high altitude reconnaissance flights. The advantage of using less time to prepare or using the same time to better prepare for a mission involving decompression to 30,000 ft is in better utilization of the available crew duty period. Potential future applications may include more effective preoxygenation procedures for airdrop operations.

REFERENCES

1. Behnke, A.R. The application of measurements of nitrogen elimination to the problem of decompressing divers. U.S. Naval Medical Bulletin. 35:219-40. 1937.
2. Bendrick, G.A, M.J. Ainscough, A.A. Pilmanis, and R.U. Bisson. Prevalence of decompression sickness symptoms in U-2 pilots. Aviat. Space Environ. Med. 67:199-206. 1996.
3. Ferris, E.B., J.P. Webb, H.W. Ryder, G.L. Engel, J. Romano, and M.A. Blankenhorn. The protective value of preflight oxygen inhalation at rest against decompression sickness. Comm. Aviat. Med. Report #132. 8pp. 1943.
4. Gray, J.S. The effect of varying periods of denitrogenation on aeroembolism in cadets. SAM Report, Project #164. 9pp. 1943.
5. Kannan, N., D.A. Raychaudhuri, and A.A. Pilmanis. A loglogistic model for altitude decompression sickness. Aviat. Space Environ. Med. 69:965-70. 1998.
6. Pilmanis, A.A and JT Webb. Altitude decompression sickness prediction: A simplified approach. 1995 SAFE Symposium Proceedings. 501-9. 1995.
7. Waligora, J.M., D.J. Horrigan, and J. Conkin. The effect of extended oxygen prebreathing on altitude decompression sickness and venous gas bubbles. Aviat. Space Environ. Med. 58:A110-A112. 1987.
8. Webb, J.T., M.D. Fischer, C.L. Heaps, and A.A. Pilmanis. Exercise-enhanced preoxygenation increases

protection from decompression sickness. Aviat. Space Environ. Med. 67:618-24. 1996.
9. Webb, J.T. and A.A. Pilmanis. A new preoxygenation procedure for extravehicular activity (EVA). Acta Astronautica. 42:115-22. 1998.

ACKNOWLEDGMENTS

This research was sponsored, in part, by the Air Force Research Laboratory, Brooks AFB, TX, under USAF Contract F41624-97-D-6004/01.

BIOGRAPHIES

James T. Webb is a lead scientist for Wyle Laboratories in San Antonio, Texas. He has M.S. and Ph.D. degrees from the University of Washington and is board certified in Aerospace Physiology by the Aerospace Medical Association. Dr. Webb holds an Airline Transport Pilot certificate and has over 4300 flying hours including 250 combat hours in Vietnam (F-4Ds) and 2800 hours of C-141A experience. He is a past-President of the Aerospace Physiology Society (1993-1994) and the Life Sciences and Biomedical Engineering Branch (1995-1996) of the Aerospace Medical Association. Dr. Webb is a Fellow of the Aerospace Medical Association, and currently investigates decompression sickness risk at Brooks AFB, TX.

Andrew A. Pilmanis is a senior research physiologist and Chief of High Altitude Protection Research at the Air Force Research Laboratory's Biodynamics & Protection Division. He has M.S. and Ph.D. degrees in physiology from the University of Southern California (USC). He is an Associate Fellow of the Aerospace Medical Association and President-elect of the the Life Sciences and Biomedical Engineering Branch (1997-1998) of the Aerospace Medical Association. Previously, he was on the faculty of the USC School of Medicine and director of their Hyperbaric Research and Treatment Facility on Santa Catalina Island. He was Program Director (1980-1985) for the joint NOAA/USC Undersea Research Program, responsible for the design and construction of the laboratory's saturation diving system (underwater habitat), Aquarius.